CLAIMS

We claim:

1. A method of transmitting information, comprising the steps of:

(1) generating a chaotic carrier signal that causes a voltage to oscillate chaotically about a first equilibrium point in a current-voltage phase space of a circuit that exhibits a current-voltage characteristic curve on which the first equilibrium point falls; and

(2) changing, in response to an information signal, a non-reactive resistive value in the circuit and thereby causing the first equilibrium point to shift to a shifted first equilibrium point in the current-voltage phase space.

2. The method of claim 1, wherein step (1) comprises the step of generating a chaotic carrier signal that oscillates about two equilibrium points in the current-voltage phase space, and wherein step (2) comprises the step of causing both equilibrium points to shift in the current-voltage phase space.

3. The method of claim 1, wherein the circuit exhibits a piecewise-linear current-voltage characteristic comprising three linear segments, two of the linear segments having a first slope in the phase space and the third linear segment having a second slope in the phase space; and wherein step (2) comprises the step of changing either the first slope or the second slope but not both slopes in response to the information signal.

4. The method of claim 1, wherein the circuit exhibits a piecewise-linear current-voltage characteristic comprising three linear segments, two of the linear segments having a first slope in the phase space and the third linear segment having a second slope in the phase space; and wherein step (2) comprises the step of changing both the first slope and the second slope in response to the information signal.

5. The method of claim 1, wherein step (2) comprises the step of switching a non-reactive resistive element in the circuit which changes a slope of the current-voltage characteristic curve for the circuit element.

6. The method of claim 5, wherein step (2) comprises the step of switching

a resistive element in a Kennedy diode circuit.

7. The method of claim 5, wherein step (2) comprises the step of switching a resistive element in a Caltech diode circuit.

8. The method of claim 5, wherein step (2) comprises the step of switching a resistive element in an SAIC diode circuit.

9. The method of claim 1, wherein step (2) comprises the step of shorting at least two diodes arranged in opposite polarity.

10. The method of claim 1, further comprising the steps of:

(3) transmitting a signal resulting from the changed non-reactive resistive value through a communication channel;

(4) receiving the signal transmitted in step (3) in a receiver tuned to synchronize with the chaotic carrier signal generated in step (1); and

(5) providing a demodulated output containing the information signal by detecting periods of synchronization and non-synchronization with the received signal.

11. The method of claim 10, wherein:

step (3) comprises the step of transmitting a single-scroll attractor chaotic signal;

step (4) comprises the step of receiving the single-scroll attractor chaotic signal transmitted in step (3); and

step (5) comprises the step of detecting periods of synchronization and non-synchronization with the single-scroll attractor chaotic signal.

12. The method of claim 10, wherein:

step (3) comprises the step of transmitting a double-scroll attractor chaotic signal;

step (4) comprises the step of receiving the double-scroll attractor chaotic signal transmitted in step (3); and

step (5) comprises the step of detecting periods of synchronization and non-synchronization with the double-scroll attractor chaotic signal.

13. The method of claim 10, wherein:

step (3) comprises the step of transmitting a triple-scroll attractor chaotic signal;

step (4) comprises the step of receiving the triple scroll attractor chaotic transmitted in step (3); and

step (5) comprises the step of detecting periods of synchronization and non-synchronization with the triple-scroll attractor chaotic signal.

14. The method of claim 1, wherein step (2) comprises the step of changing a breakpoint voltage of a piecewise linear response curve of the circuit.

15. A chaotic transmitting circuit, comprising:

an oscillator circuit;

a resistor coupled to the oscillator circuit;

a chaotic circuit, coupled to the oscillator circuit through the resistor, wherein the chaotic circuit exhibits a current-voltage characteristic shape having a slope that intersects a load line defined by the resistor and provides an equilibrium point about which a voltage oscillates chaotically; and

means for changing the slope exhibited by the chaotic circuit in accordance with an information signal.

16. The chaotic transmitting circuit according to claim 15, wherein the oscillator circuit comprises an inductance and a first capacitance;

wherein the chaotic circuit comprises a second capacitance; and

wherein the values of the first capacitance, the second capacitance, the inductance, and the resistance are selected so as to cause the chaotic transmitting circuit to oscillate in a single-scroll attractor mode.

17. The chaotic transmitting circuit according to claim 15,

wherein the oscillator circuit comprises an inductance and a first capacitance;

wherein the chaotic circuit comprises a second capacitance; and

wherein the values of the first capacitance, the second capacitance, the inductance, and the resistance are selected so as to cause the chaotic transmitting circuit to oscillate in a double-scroll attractor mode.

18. The chaotic transmitting circuit according to claim 15, wherein the means for changing comprises means for switching a plurality of resistive values.

19. The chaotic transmitting circuit according to claim 18, wherein the means for switching shifts a voltage breakpoint on the current-voltage characteristic shape exhibited by the chaotic circuit.

20. The chaotic transmitting circuit according to claim 18, wherein the means for switching shifts a slope of a piecewise linear current-voltage characteristic shape exhibited by the chaotic circuit.

21. The chaotic transmitting circuit according to claim 18, wherein the means for switching shifts two slopes of the current-voltage characteristic shape exhibited by the chaotic circuit.

22. The chaotic transmitting circuit according to claim 15, wherein the chaotic circuit comprises circuit elements having values selected so as to cause the chaotic transmitting circuit to oscillate about a single-scroll attractor.

23. The chaotic transmitting circuit according to claim 22, wherein the means for switching shifts an equilibrium point of the single-scroll attractor among at least three different positions on the current-voltage characteristic shape, each position corresponding to a different information symbol contained in the information signal.

24. A system comprising a chaotic transmitting circuit according to claim 15 and further comprising a chaotic receiving circuit comprising circuit components matched to synchronize with the chaotic transmitting circuit.

25. A chaotic transmitting circuit, comprising:

an oscillator circuit;

a resistor coupled to the oscillator circuit;

a chaotic circuit coupled to the oscillator circuit through the resistor, wherein the chaotic circuit exhibits a current-voltage characteristic shape having a slope that intersects a load line defined by the resistor and provides an equilibrium point about which a voltage oscillates chaotically; and

a switch coupled to the chaotic circuit, wherein the switch changes a nonreactive resistive value in the chaotic circuit in accordance with an information

signal and thereby causes the first equilibrium point to shift to a shifted first equilibrium point.

26. The chaotic transmitting circuit of claim 25, wherein the chaotic circuit comprises a diode circuit that exhibits a negative piecewise linear resistance.

27. The chaotic transmitting circuit of claim 25, wherein the chaotic circuit comprises:

a first op amp coupled across the oscillator circuit through the resistor, wherein the first op amp is further coupled to a first group of three resistors, a first of which is coupled between an output of the first op amp and a positive input terminal thereof; a second of which is coupled between the output of the first op amp and a negative input terminal thereof; and a third of which is coupled between the negative input terminal and a ground; and

a second op amp coupled across the oscillator circuit through the resistor, wherein the second op amp is further coupled to a second group of three resistors, a first of which is coupled between an output of the second op amp and a positive input terminal thereof; a second of which is coupled between the output of the second op amp and a negative input terminal thereof; and a third of which is coupled between the negative input terminal and the ground.

28. The chaotic transmitting circuit of claim 27, wherein the switch changes a non-reactive resistive value between the negative input terminal of the second op amp and the ground.

29. The chaotic transmitting circuit of claim 25, wherein the chaotic circuit element comprises:

a first diode arranged in a forward polarity across the oscillator circuit through a first resistor and coupled to a first voltage supply through a second resistor;

a second diode arranged in a reversed polarity across the oscillator circuit through a third resistor and coupled to a second voltage supply through a fourth resistor; and

an op amp coupled to a first group of three resistors, a first of which is coupled between an output of the op amp and a positive input terminal thereof; a

second of which is coupled between the output of the op amp and a negative input terminal thereof; and a third of which is coupled between the negative input terminal and ground.

30. The chaotic transmitting circuit of claim 29,

wherein the switch modifies a resistive value between the negative input terminal of the op amp and ground.

31. The chaotic transmitting circuit of claim 25, wherein the chaotic circuit element comprises:

two forward biased diodes coupled across the oscillator circuit through a first resistor;

two reverse biased diodes coupled across the oscillator circuit through a second resistor; and

an op amp coupled across the oscillator circuit through a resistive feedback network.

32. The chaotic transmitting circuit of claim 25, wherein the chaotic circuit element comprises two diodes arranged in opposite polarity across the oscillator circuit through corresponding resistors, wherein the switch shorts the two diodes in response to the information signal and causes the chaotic transmitting circuit to stop oscillating in a chaotic manner.

33. The chaotic transmitting circuit of claim 25,

wherein the oscillator and chaotic circuit comprise circuit elements having values selected so as to cause the chaotic transmitting circuit to oscillate in a single-scroll attractor mode.

34. The chaotic transmitting circuit of claim 33,

wherein the oscillator circuit comprises an inductance and a first capacitance;

wherein the chaotic circuit comprises a second capacitance; and

wherein the values of the first capacitance, the second capacitance, the inductance, and the resistance are selected so as to cause the chaotic transmitting circuit to oscillate in a single-scroll attractor mode.

35. The chaotic transmitting circuit of claim 25,

wherein the oscillator and chaotic circuit comprise circuit elements having values selected so as to cause the chaotic transmitting circuit to oscillate in a double-scroll attractor mode.

36. A nonlinear circuit element for use in a chaotic transmitter, comprising:

a first pair of diodes coupled in series and biased in a forward direction with respect to first and second circuit terminals;

a second pair of diodes coupled in series and biased in a reverse direction with respect to the first and second circuit terminals;

a first resistor coupled between the first pair of diodes and one of the circuit terminals;

a second resistor coupled between the second pair of diodes and one of the circuit terminals; and

an op amp coupled between the first and second circuit terminals through a resistive network;

wherein the first resistor, the second resistor, and the resistive network have values selected to bias the nonlinear circuit element such that it exhibits a piecewise linear current-voltage characteristic across the first and second terminals.

37. The nonlinear circuit element of claim 36, further comprising:

a fourth resistor coupled to the resistive network; and

a switch that couples the fourth resistor into the resistive network, thus changing a slope of the piecewise linear current-voltage characteristic of the nonlinear circuit element in response to an information signal.

38. A communication system comprising a transmitter and a receiver, wherein the transmitter comprises

an oscillator circuit;

a resistor coupled to the oscillator circuit;

a chaotic circuit coupled to the oscillator circuit through the resistor, wherein the chaotic circuit causes a voltage to oscillate about a first equilibrium point on a current-voltage characteristic curve of the chaotic circuit element; and

a switch coupled to the chaotic circuit element, wherein the switch changes

a nonreactive resistive value in the chaotic circuit in accordance with an information signal and thereby causes the first equilibrium point to shift to a shifted first equilibrium point; and wherein the receiver comprises

a second oscillator circuit;

a second resistor coupled to the second oscillator circuit;

a second chaotic circuit coupled to the second oscillator circuit through the second resistor; and

a detector coupled to the second oscillator circuit and the second chaotic circuit;

wherein the second oscillator circuit and the second chaotic circuit comprise circuit components selected such that they cause the receiver to synchronize with the transmitter when the transmitter transmits according to the first equilibrium point; and

wherein the detector detects whether the receiver is synchronized and, in response to detecting synchronization, generates a signal.

39. The system of claim 38, wherein the transmitter and the receiver each oscillate chaotically about a single-scroll attractor.

40. The system of claim 38, wherein the transmitter and the receiver each oscillate chaotically about double-scroll attractors.

41. A chaotic receiver comprising:

an input terminal for receiving a chaotically modulated signal;

an oscillating circuit coupled to the input terminal;

a chaotic circuit comprising a capacitor and a negative resistance element, wherein the chaotic circuit is coupled to the oscillating circuit through a resistor, wherein the chaotic circuit causes a voltage to oscillate about an equilibrium point corresponding to a current-voltage characteristic curve of the negative resistance element;

a synchronizing resistor coupled between the input terminal and the negative resistance element; and

a comparator, coupled across the synchronizing resistor, wherein the

comparator generates an output signal when a voltage drop across the synchronizing resistor reaches a predetermined level; and

wherein the synchronizing resistor has a value that satisfies the relation

$$Rsync \leq (1/(2f_{LC} \times C_1))$$

where f_{LC} is the fundamental frequency of the oscillator circuit, and where C_1 is the capacitance of the capacitor.

42. A chaotic receiver comprising:

an input terminal that receives a modulated chaotic signal;

an oscillator coupled to the input terminal;

a chaotic circuit comprising a capacitor and a negative resistance circuit;

a gain control amplifier coupled between the oscillator and the chaotic circuit, wherein the gain control amplifier amplifies a voltage present at the oscillator before it reaches the chaotic circuit;

a synchronizing resistor coupled between the input terminal and the chaotic circuit; and

a detection circuit, coupled to the synchronizing resistor, wherein the detection circuit detects periods of synchronization and non-synchronization between the modulated chaotic signal and the chaotic circuit and generates an output corresponding to periods of synchronization and non-synchronization.

43. The chaotic receiver of claim 42, wherein the gain control amplifier provides an amplification of between 2.4 dB to 3 dB.

44. A chaotic communication system comprising:

a transmitter that generates a chaotic carrier signal modulated in accordance with an information signal; and

a receiving system having an input terminal that receives the chaotic carrier signal modulated by the transmitter, wherein the receiving system comprises

an oscillator subsystem coupled to the input terminal;

a gain control amplifier coupled to the output of the oscillator subsystem;

a chaotic subsystem coupled to the output of the gain control amplifier;

a synchronizing subsystem coupled to the chaotic subsystem and to the input terminal, which causes the chaotic subsystem to synchronize to the chaotic carrier signal; and

a detector coupled to the chaotic subsystem and the input terminal, wherein the detector detects periods of synchronization and non-synchronization;

wherein the gain control amplifier amplifies a signal produced by the oscillator subsystem and drives the chaotic subsystem with the amplified signal, and wherein the chaotic subsystem generates a signal that synchronizes with the modulated chaotic signal when the transmitter transmits a symbol of information.

45. A chaotic transmitter, comprising:

an oscillator;

a resistor coupled to the oscillator;

a chaotic circuit comprising a negative resistance, wherein the chaotic circuit is coupled to the oscillator circuit through the resistor;

an isolation amplifier coupled to the chaotic circuit;

a filter coupled to the output of the isolation amplifier that limits a frequency bandwidth present at the chaotic circuit; and

means for modulating a circuit element of the chaotic transmitter in accordance with an information signal.

46. The chaotic transmitter of claim 45, wherein the filter comprises a lowpass filter.

47. The chaotic transmitter of claim 45, wherein the filter comprises a bandpass filter.

48. The chaotic transmitter of claim 45, wherein the filter matches a bandwidth of the chaotic transmitter to a transmission medium.

49. The chaotic transmitter of claim 45, wherein the means for modulating comprises a switch that switches a reactive component in the oscillator, thereby changing a strange attractor trajectory generated by the transmitter.

50. The chaotic transmitter of claim 45, wherein the means for modulating comprises a switch that switches a reactive component in the chaotic circuit, thereby

changing a strange attractor trajectory generated by the transmitter.

51. The chaotic transmitter of claim 45, wherein the means for modulating comprises a switch that changes a non-reactive resistive value in the chaotic circuit, thereby changing a current-voltage characteristic of the negative resistive element.

52. The chaotic transmitter of claim 51, wherein the transmitter oscillates about a single-scroll attractor.

53. The chaotic transmitter of claim 51, wherein the transmitter oscillates about a double-scroll attractor.

54. A chaotic receiver, comprising:

an input terminal that receives a modulated chaotic signal;

a first filter, coupled to the input terminal, which filters the modulated chaotic signal and produces a filtered modulated chaotic signal;

an oscillator coupled to an output of the first filter;

a chaotic circuit comprising a negative resistor, wherein the chaotic circuit is coupled to the oscillator;

a synchronizing circuit coupled between the first filter and the chaotic circuit, wherein the synchronizing circuit generates a voltage difference in response to an out-of-synchronization condition between the filtered modulated chaotic signal and the chaotic circuit;

a second filter, coupled to a first portion of the synchronizing circuit, which filters a buffered version of the filtered modulated chaotic signal;

a third filter, coupled to a second portion of the synchronizing circuit, which filters a signal generated by the chaotic circuit; and

a detection circuit, coupled to the second and third filters, wherein the detection circuit detects periods of synchronization and non-synchronization between the modulated chaotic signal and the chaotic circuit and generates an output corresponding to periods of synchronization and non-synchronization.

55. A chaotic receiver, comprising:

an input terminal that receives a modulated chaotic signal;

a first filter, coupled to the input terminal, which filters the modulated chaotic

signal and produces a filtered modulated chaotic signal;

an oscillator coupled to the input terminal;

a chaotic circuit comprising a circuit element that exhibits a nonlinear current-voltage characteristic, wherein the chaotic circuit is coupled to the oscillator;

a synchronizing circuit coupled between the first filter and the chaotic circuit, wherein the synchronizing circuit generates a voltage difference in response to an out-of-synchronization condition between the filtered modulated chaotic signal and the chaotic circuit;

a second filter, coupled to a first portion of the synchronizing circuit, which filters a buffered version of the filtered modulated chaotic signal;

a third filter, coupled to a second portion of the synchronizing circuit, which filters a signal generated by the chaotic circuit; and

a detection circuit, coupled to the second and third filters, wherein the detection circuit detects periods of synchronization and non-synchronization between the modulated chaotic signal and the chaotic circuit and generates an output corresponding to periods of synchronization and non-synchronization.

56. A chaotic receiver, comprising:

an input terminal that receives a modulated chaotic signal;

a first filter, coupled to the input terminal, which filters the modulated chaotic signal and produces a filtered modulated chaotic signal;

an oscillating circuit coupled to the first filter;

a chaotic circuit comprising a circuit element that exhibits a nonlinear current-voltage characteristic, wherein the chaotic circuit is coupled to the oscillating circuit through a second filter;

a third filter, coupled to the output of the first filter, which further filters the output of the first filter;

a synchronizing circuit coupled between the third filter and the chaotic circuit, wherein the synchronizing circuit generates a voltage difference in response to an out-of-synchronization condition between a signal from the third filter and the chaotic circuit;

a fourth filter, coupled to a first portion of the synchronizing circuit, which filters a buffered version of the filtered modulated chaotic signal;

a fifth filter, coupled to a second portion of the synchronizing circuit, which filters a signal generated by the chaotic circuit; and

a detection circuit, coupled to the fourth and fifth filters, wherein the detection circuit detects periods of synchronization and non-synchronization between the modulated chaotic signal and the chaotic circuit and generates an output corresponding to periods of synchronization and non-synchronization.

57. A chaotic telephone device comprising:

a chaotic transmitter that receives a first information signal and generates in response thereto a first chaotic trajectory shifted signal modulated in accordance with the first information signal;

a chaotic receiver that receives a second chaotic trajectory shifted signal modulated in accordance with a second information signal and generates in response thereto a demodulated version of the second chaotic trajectory shifted signal; and

an interface circuit that couples the chaotic transmitter and chaotic receiver to a radio-frequency telephone circuit, wherein the radio-frequency telephone circuit communicates with a ground-based telephone network through one or more radio frequency transmission stations.

58. The chaotic telephone device of claim 57, wherein the chaotic transmitter and the chaotic receiver respectively modulate and demodulate signals at baseband frequencies.

59. The chaotic telephone device of claim 57, wherein the chaotic transmitter and the chaotic receiver respectively modulate and demodulate signals at an intermediate frequency band that falls between the frequency band of the first and second information signals and a radio frequency band used by the radio-frequency telephone circuit.

60. The chaotic telephone device of claim 57, wherein the chaotic transmitter and the chaotic receiver respectively modulate and demodulate signals at a radio frequency band used by the radio-frequency telephone circuit.

61. The chaotic telephone device of claim 57, wherein the chaotic transmitter and the chaotic receiver respectively modulate and demodulate signals in a single-scroll strange attractor phase space.

62. The chaotic telephone device of claim 57, wherein the chaotic transmitter and the chaotic receiver respectively modulate and demodulate signals in a double-scroll strange attractor phase space.

63. The chaotic telephone device of claim 57, wherein the chaotic transmitter modulates using a first set of strange attractor parameters that match a set of strange attractor parameters in a corresponding receiver associated with the one or more radio frequency transmission stations; and wherein the chaotic receiver demodulates using a second set of strange attractor parameters in a corresponding transmitter associated with the one or more radio frequency transmission stations.

64. The chaotic telephone device of claim 57, wherein the chaotic receiver comprises:

an oscillator;

a chaotic circuit comprising a circuit element that exhibits a nonlinear current-voltage characteristic; and

a gain control amplifier coupled between the oscillator and the chaotic circuit, wherein the gain control amplifier amplifies a voltage present at the oscillator before it reaches the chaotic circuit.

65. The chaotic telephone device of claim 64,

wherein the chaotic receiver further comprises a synchronizing resistor coupled between an input of the chaotic receiver and the chaotic circuit; and

further comprising a detection circuit, coupled to the synchronizing resistor, wherein the detection circuit detects periods of synchronization and non-synchronization between the second modulated chaotic signal and the chaotic circuit and generates an output corresponding to periods of synchronization and non-synchronization.

66. The chaotic telephone device of claim 57, wherein the chaotic transmitter comprises:

an oscillator circuit;

a resistor coupled to the oscillator circuit;

a chaotic circuit comprising a circuit element that exhibits a nonlinear current-voltage characteristic, wherein the chaotic circuit is coupled to the oscillator circuit through the resistor;

an isolation amplifier coupled to the chaotic circuit;

a filter coupled to the output of the isolation amplifier that limits a frequency bandwidth present at the chaotic circuit; and

means for modulating a circuit element of the chaotic transmitter in accordance with the first information signal.

67. A method of communicating between a portable telephone device and a base station, comprising the steps of:

(1) generating an information signal at the portable telephone device;

(2) modulating a chaotic carrier signal with the information signal using a chaotic trajectory shifting technique;

(3) transmitting the chaotic trajectory shift-keyed signal generated in step (2) to the base station; and

(4) in the base station, demodulating the transmitted signal to recover the information signal.

68. The method of claim 67, wherein step (2) comprises the step of changing a non-reactive resistive value in a chaotic circuit element to cause a strange attractor trajectory shift.

69. The method of claim 67, wherein step (2) comprises the step of generating a chaotic carrier signal that oscillates about two equilibrium points in a current-voltage phase space, and further comprising the step of causing both equilibrium points to shift in the current-voltage phase space.

70. The method of claim 67, wherein step (2) comprises the step of using a nonlinear circuit element that exhibits a piecewise linear current-voltage characteristic comprising three linear segments, two of the segments having a first slope in the phase space and the third segment having a second slope in the phase

space, and where step (2) comprises the step of changing either the first slope or the second slope but not both slopes in response to the information signal.

71. The method of claim 67, wherein step (4) comprises the step of detecting periods of synchronization and non-synchronization between the signal the received chaotic trajectory shift-keyed signal generated and a locally-generated chaotic signal using a circuit matched to a transmitter used to transmit in step (3).

72. The method of claim 67, wherein step (2) comprises the steps of:

(a) modulating at a baseband frequency level; and

(b) frequency translating the modulated baseband signal to a radio frequency band.

73. The method of claim 67, wherein step (2) comprises the steps of:

(a) modulating at an intermediate frequency band which falls between a frequency band of the information signal and a radio frequency band used by transmitting equipment; and

(b) frequency translating the modulated intermediate frequency signal to the radio frequency band of the transmitting equipment.

74. The method of claim 67, wherein step (2) comprises the steps of:

(a) modulating the information signal directly to a radio frequency band; and

(b) directly transmitting the modulated information signal in the radio frequency band.

75. A chaotic transmitter, comprising:

a first chaotic circuit that generates a first chaotic signal having a first strange attractor trajectory;

a second chaotic circuit that generates a second chaotic signal having a second strange attractor trajectory different from that of the first strange attractor trajectory;

a switch coupled to the first and second chaotic circuits, wherein the switch selects either the first chaotic signal or the second chaotic signal in response to an information signal; and

a low-pass filter coupled to the output of the switch.

76. The chaotic transmitter of claim 75, wherein the first and second chaotic circuits each generate a single-scroll strange attractor chaotic signal.

77. The chaotic transmitter of claim 75, wherein the first and second chaotic circuits each generate a double-scroll strange attractor chaotic signal.

78. The chaotic transmitter of claim 75, further comprising a summing circuit coupled between the switch and the low-pass filter, wherein the summing circuit sums the output from the switch.

79. A method of transmitting an information signal, comprising the steps of:

(1) generating a first chaotic signal comprising at least one strange attractor that oscillates about a first equilibrium point;

(2) generating a second chaotic signal comprising at least a second strange attractor that oscillates about a second equilibrium point;

(3) in response to the information signal, selecting an output of either the first chaotic signal or the second chaotic signal; and

(4) transmitting the selected output from step (3).

80. The method of claim 79, further comprising the step of filtering the output selected in step (3).

81. The method of claim 79, wherein steps (1) and (2) each comprise the step of generating a single-scroll strange attractor chaotic signal.

82. The method of claim 79, wherein steps (1) and (2) each comprise the step of generating a double-scroll strange attractor chaotic signal.

83. A chaotic receiver, comprising:

an input terminal that receives a modulated chaotic signal;

an oscillator circuit coupled to the input terminal;

a first chaotic circuit coupled to the oscillator circuit and tuned to a first strange attractor;

a second chaotic circuit coupled to the oscillator circuit and tuned to a second strange attractor; and

means for detecting a difference between the modulated chaotic signal received at the input terminal and respective signals generated by the first and second

chaotic circuits.

84. The chaotic receiver of claim 83, further comprising a third chaotic circuit coupled to the oscillator circuit and tuned to a third strange attractor; wherein the means for detecting a difference further detects a difference between the modulated chaotic signal received at the input terminal and a signal generated by the third chaotic circuit.

85. A method of demodulating a signal modulated according to a chaotic trajectory shift-keying technique, comprising the steps of:

(1) receiving a modulated chaotic signal modulated according to a chaotic trajectory shift-keying technique;

(2) using the modulated chaotic signal to drive an oscillator;

(3) using the modulated chaotic signal and an output of the oscillator to drive a first chaotic circuit tuned to a first strange attractor;

(4) using the modulated chaotic signal and an output of the oscillator circuit to drive a second chaotic circuit tuned to a second strange attractor; and

(5) detecting a difference between the modulated chaotic signal and respective signals generated by the first and second chaotic circuits.

86. The method of claim 85, further comprising the step of using the modulated chaotic signal and an output of the oscillator circuit to drive a third chaotic circuit tuned to a third strange attractor, and wherein step (5) comprises the step of detecting a difference between the modulated chaotic signal and a signal generated by the third chaotic circuit.

87. The receiver of claim 83, wherein the means for detecting comprises:

a plurality of synchronizing resistors each of which generates a voltage drop in response to a difference between the modulated chaotic signal and a corresponding one of the first and second chaotic circuits;

means for buffering the plurality of synchronizing resistors and generating buffered outputs therefrom;

means for attenutating the buffered outputs; and

means for subtracting the buffered outputs to generate a detected signal.

88. The method of claim 85, wherein step (5) comprises the steps of:

(a) generating a voltage drop in response to a difference between the modulated chaotic signal and a corresponding one of the first and second chaotic circuits;

(b) buffering the plurality of synchronizing resistors and generating buffered outputs therefrom;

(c) attenuating the buffered outputs; and

(d) subtracting the buffered outputs to generate a detected signal.

89. The chaotic receiver of claim 83, further comprising means for generating an absolute value of the difference signal.

90. The method of claim 85, further comprising the step of:

(6) generating an absolute value signal from the difference detected in step (5).

91. The chaotic receiver of claim 83, wherein the means for detecting a difference comprises at least two synchronizing resistors, each respectively coupled between the oscillator and one of the first and second chaotic circuits, the chaotic receiver further comprising:

first and second subtractor circuits, each coupled across a corresponding one of the two synchronizing resistors;

a third subtractor circuit, coupled to the first and second subtractor circuits, wherein the third subtractor circuit generates a difference signal from the first and second subtractor circuits;

an absolute value circuit, coupled to the third subtractor circuit, which generates an absolute value signal from the third subtractor circuit; and

a squaring circuit that generates a squared version of the absolute value signal.

92. The method of claim 85, wherein step (5) comprises the step of generating a voltage drop in response to a difference between the modulated chaotic signal and a corresponding one of the first and second chaotic circuits, the method further comprising the steps of:

(6) generating first and second difference signals corresponding to first and second voltage drops from the first and second chaotic circuits;

(7) subtracting the first and second difference signals and generating a third difference signal therefrom;

(9) generating an absolute value signal from the third difference signal; and

(10) generating a squared version of the absolute value signal.

93. The chaotic receiver of claim 83, wherein the means for detecting a difference comprises at least two synchronizing resistors, each respectively coupled between the oscillator and one of the first and second chaotic circuits, the chaotic receiver further comprising:

first and second subtractor circuits, each coupled across a corresponding one of the two synchronizing resistors;

first and second absolute value circuits, each coupled to a corresponding one of the first and second subtractor circuits;

a third subtractor circuit, coupled to the first and second absolute value circuits, which generates a subtracted absolute value signal; and

a squaring circuit that generates a squared version of the subtracted absolute value signal.

94. The method of claim 85, wherein step (5) comprises the step of generating a voltage drop in response to a difference between the modulated chaotic signal and a corresponding one of the first and second chaotic circuits, the method further comprising the steps of:

(6) generating first and second difference signals corresponding to first and second voltage drops from the first and second chaotic circuits;

(7) generating first and second absolute value signals from the first and second difference signals;

(8) subtracting the first and second first and second absolute value signals and generating therefrom a subtracted absolute value signal; and

(9) generating a squared version of the subtracted absolute value signal.

95. A chaotic receiver, comprising:

an input terminal that receives a modulated chaotic signal;

an oscillator coupled to the input terminal;

a first chaotic circuit coupled to the oscillator and tuned to a first strange attractor;

a second chaotic circuit coupled to the oscillator circuit and tuned to a second strange attractor; and

a detector circuit coupled to the first and second chaotic circuits, wherein the detector circuit subtracts signals present at the first and second chaotic circuits and generates an absolute value signal based on the subtracted signal.

96. A method of demodulating a signal modulated according to a trajectory shift-keying technique, comprising the steps of:

(1) receiving a modulated chaotic signal;

(2) using the modulated chaotic signal to drive an oscillator circuit;

(3) using the modulated chaotic signal and an output of the oscillator circuit to drive a first chaotic circuit comprising a first nonlinear circuit element and tuned to a first strange attractor;

(4) using the modulated chaotic signal and an output of the oscillator circuit to drive a second chaotic circuit comprising a second nonlinear circuit element and tuned to a second strange attractor; and

(5) detecting a difference between first and second signals present at the first and second chaotic circuits, respectively, by subtracting the first and second signals and generating an absolute value thereof.

97. The method of claim 1, wherein step (2) comprises the step of continuously varying the non-reactive resistive value over a chaotic operating region in accordance with the information signal.

98. The method of claim 1, wherein step (2) comprises the step of changing the non-reactive resistive value to one of a plurality of uniquely coded vectors within a chaotic operating region which, when received at a matched receiver, will generate a corresponding unique code.

99. The apparatus of claim 15, wherein the means for changing continuously varies the non-reactive resistance over a chaotic operating region in accordance with the information signal.

100. The apparatus of claim 15, wherein the means for changing sets the non-reactive resistive value to one of a plurality of uniquely coded vectors within a chaotic operating region which, when received at a matched receiver, will generate a corresponding unique code.

101. The apparatus of claim 25, wherein the switch continuously varies the non-reactive resistance over a chaotic operating region in accordance with the information signal.

102. The apparatus of claim 25, wherein the switch sets the non-reactive resistive value to one of a plurality of uniquely coded vectors within a chaotic operating region which, when received at a matched receiver, will generate a corresponding unique code.

103. A method of transmitting information, comprising the steps of:

(1) in response to receiving a time-varying N-bit code representing a unit of information, selecting a corresponding one of a plurality of 2^N transmitters each of which generates a chaotic strange attractor signal that is distinct from others in the plurality of 2^N transmitters; and

(2) transmitting through a communications channel the chaotic strange attractor signal selected in step (1).

104. The method of claim 103, wherein N is at least 2.

105. The method of claim 103, wherein N is at least 8.

106. (plus reception method, DEH/CPG) The method of claim 103, further comprising the steps of:

(3) receiving the chaotic strange attractor signal transmitted in step (2);

(4) matching the signal received in step (3) to one of a plurality of 2^N receivers each of which is matched to a corresponding one of the plurality of 2^N transmitters; and

(5) on the basis of the receiver matched in step (4), recovering the N-bit code received in step (1).

107. A method of recovering information transmitted through a communication channel, comprising the steps of:

(1) receiving a time-varying signal comprising discrete portions of each of a plurality of chaotic strange attractor signals;

(2) matching the signal received in step (1) to one of a plurality of 2^N receivers each of which is tuned to a different strange attractor signal; and

(3) on the basis of the receiver matched in step (2), generating an N-bit code.

108. The method of claim 107, wherein N is at least 2.

109. The method of claim 107, wherein N is at least 8.

110. A transmitting system capable of transmitting N bits of information, comprising:

a plurality of 2^N transmitters each of which generates a chaotic strange attractor signal that is distinct from others in the plurality of 2^N transmitters;

a switch which, in response to receiving a time-varying N-bit code representing a unit of information, selects a corresponding one of the plurality of 2^N transmitters; and

a transmission circuit that transmits the selected chaotic strange attractor signal across a transmission channel.

111. A receiving system comprising:

a receiving circuit that receives a time-varying signal comprising a plurality of discrete portions of each of a plurality of chaotic strange attractor signals;

a plurality of 2^N receivers each of which is tuned to one of a corresponding number of 2^N transmitters;

a plurality of detectors each of which detects whether a corresponding one of the plurality of 2^N receivers has received a matching signal; and

a switching circuit which, in response to one of the detectors detecting a corresponding match, generates an N-bit code representing a transmitted unit of information.

112. An information transmission system comprising a transmitting system according to claim 110 and a receiving system, wherein the receiving system comprises:

a receiving circuit that receives a time-varying signal comprising a plurality of discrete portions of each of a plurality of chaotic strange attractor signals;

a plurality of 2^N receivers each of which is tuned to one of the 2^N transmitters;

a plurality of detectors each of which detects whether a corresponding one of the plurality of 2^N receivers has received a matching signal; and

a switching circuit which, in response to one of the detectors detecting a corresponding match, generates an N-bit code representing a transmitted unit of information.

113. A method according to claim 1, wherein step (1) comprises the step of using a digitally implemented nonlinear circuit having a current-voltage characteristic that satisfies the equation $I = -aV-bV^3$, where a and b are constants.

114. The chaotic transmitting circuit of claim 15, wherein the chaotic circuit comprises a digitally implemented circuit having a current-voltage characteristic that satisfies the equation $I = -aV-bV^3$, where a and b are constants.

115. The chaotic transmitting circuit of claim 25, wherein the chaotic circuit comprises a digitally implemented circuit having a current-voltage characteristic that satisfies the equation $I = -aV-bV^3$, where a and b are constants.

116. A chaotic receiver comprising:

an input terminal that receives a modulated chaotic signal;

an oscillator circuit coupled to the input terminal and driven by the modulated chaotic signal;

a chaotic circuit comprising an upper slope circuit that implements a first current-voltage function in an upper quadrant of a current-voltage response plane and a lower slope circuit that implements a second current-voltage function in a lower quadrant of the current-voltage response plane, wherein the first and second current-voltage functions have a different voltage offset, and wherein the upper and lower slope circuits cooperate with the oscillator circuit to generate a local chaotic signal;

a synchronizing circuit, coupled to the oscillator circuit and the chaotic circuit, wherein the synchronizing circuit detects differences between the modulated chaotic signal at the input terminal and the local chaotic signal; and

a detector coupled to the synchronizing circuit which detects periods of synchronization and non-synchronization.

117. The chaotic receiver of claim 116, wherein the upper and lower slope circuits each comprise a voltage source coupled to a negative resistance circuit.

118. The chaotic receiver of claim 116, further comprising:

a first analog-to-digital converter coupled to the oscillator circuit;

a second analog-to-digital converter coupled to the upper slope circuit; and

a third analog-to-digital converter coupled to the lower slope circuit;

wherein the detector detects periods of synchronization and non-synchronization with respect to the output of each of the first, second, and third analog-to-digital converters.

119. The chaotic receiver of claim 116, further comprising:

a first filter, coupled between the input terminal and the oscillator circuit, wherein the first filter filters the modulated chaotic signal and produces a filtered modulated chaotic signal;

a second filter, coupled to a first portion of the synchronizing circuit, wherein the second filter filters a buffered version of the filtered modulated chaotic signal; and

a third filter, coupled to a second portion of the synchronizing circuit, wherein the third filter filters a signal generated by the chaotic circuit; and

wherein the detector is coupled to respective outputs of the second and third filters.

120. The chaotic receiver of claim 116, further comprising:

a first filter, coupled between the input terminal and the synchronizing circuit, wherein the first filter filters the modulated chaotic signal and produces a filtered modulated chaotic signal;

a second filter, coupled to a first portion of the synchronizing circuit, wherein

the second filter filters a buffered version of the filtered modulated chaotic signal; and

a third filter, coupled to a second portion of the synchronizing circuit, wherein the third filter filters a signal generated by the chaotic circuit; and

wherein the detector is coupled to respective outputs of the second and third filters.

121. The chaotic receiver of claim 116, further comprising:

a first filter, coupled between the input terminal and the oscillator circuit, wherein the first filter filters the modulated chaotic signal and produces a filtered modulated chaotic signal;

a second filter coupled between the chaotic circuit and the oscillating circuit;

a third filter, coupled to an output of the first filter, which further filters the output of the first filter;

wherein the synchronizing circuit is coupled between the third filter and the chaotic circuit, and wherein the synchronizing circuit generates a voltage difference in response to an out-of-synchronization condition between a signal from the third filter and the chaotic circuit;

a fourth filter, coupled to a first portion of the synchronizing circuit, which filters a buffered version of the filtered modulated chaotic signal; and

a fifth filter, coupled to a second portion of the synchronizing circuit, which filters a signal generated by the chaotic circuit;

wherein the detection circuit is coupled to respective outputs of the fourth and fifth filters.

122. The apparatus of claim 116, wherein the upper slope circuit satisfies the relation I = GbV + GaVbp – GbVbp; wherein the lower slope circuit satisfies the relation I = GbV – GaVbp + GbVb, where I is the current through each respective slope circuit, Gb is a first slope constant, V is the voltage across the respective slope circuit, Ga is a second slope constant, and Vbp is a breakpoint voltage.

123. A method of demodulating a chaotically modulated signal, comprising the steps of:

(1) receiving the chaotically modulated signal;

(2) applying the signal received in step (1) to an oscillator through a resistor that defines a load line;

(3) applying the signal applied to the oscillator in step (2) to first and second slope detector circuits each of which defines a linear current-voltage function that intercepts the load line in a different quadrant of a current-voltage plane;

(4) applying respective outputs of the first and second slope detector circuits to a synchronizing resistor circuit that generates voltage differences corresponding to differences between each respective slope detector circuit and the chaotically modulated signal received in step (1); and

(5) detecting an output from the synchronizing resistor circuit to provide a demodulated signal.

124. The method of claim 123, wherein step (4) comprises the step of using at least one slope detector circuit that satisfies the relation $I = GbV - GaVbp + GbVb$, where I is the current through the slope detector circuit, Gb is a first slope constant, V is the voltage across the slope detector circuit, Ga is a second slope constant, and Vbp is a breakpoint voltage.

125. The method of claim 1, wherein step (1) comprises the step of using a circuit that exhibits a linear slope in one quadrant of the current-voltage characteristic curve, and wherein step (2) comprises the step of changing the linear slope in the one quadrant.

126. The apparatus of claim 15, wherein the means for changing comprises a voltage source and a switch that shifts a slope in one quadrant of the current-voltage characteristic shape.

127. The apparatus of claim 25, wherein the switch switches a voltage source to shift to the shifted first equilibrium point.

128. The apparatus of claim 75, wherein the first chaotic circuit exhibits a first current slope that is offset to intersect a load line in an upper quadrant of a current-voltage characteristic curve; and wherein the second chaotic circuit exhibits a second current slope that is offset to intersect the load line in a lower quadrant of

the current-voltage characteristic curve.

129. The method of claim 79, wherein step (1) comprises the step of generating a first chaotic signal that oscillates about a first equilibrium point in an upper quadrant of a current-voltage phase space of a chaotic circuit element, and wherein step (2) comprises the step of generating a second chaotic signal that oscillates about a second equilibrium point in a lower quadrant of the current-voltage phase space.

130. The method of claim 125, further comprising the step of filtering an output of the circuit to limit its frequency bandwidth.

131. The apparatus of claim 126, further comprising a filter coupled to an output of the chaotic circuit that limits a frequency bandwidth thereof.

132. The apparatus of claim 127, further comprising a filter coupled to an output of the chaotic circuit that limits a frequency bandwidth thereof.

133. The chaotic receiver of claim 116, wherein the upper and lower slope circuits each implement current-voltage functions having the same positive slope.

134. The chaotic receiver of claim 133, wherein each of the upper and lower slope circuits define asymptotically stable intersection points with a negative resistive load line.

135. A method of demodulating a chaotically modulated signal, comprising the steps of:

(1) receiving the chaotically modulated signal;

(2) applying the signal received in step (1) to an oscillator through a resistor that defines a current-voltage load line;

(3) applying the signal applied to the oscillator in step (2) to a slope detector circuit that exhibits a current slope function opposite in polarity to that of the load line and which intersects the load line at an equilibrium point corresponding to an equilibrium point of a transmitter;

(4) generating a difference signal representing a difference between the chaotically modulated signal received in step (1) and the output of the slope detector circuit; and

(5) recovering an information signal on the basis of the difference signal generated in step (4).

136. The method of claim 135, wherein step (3) comprises the step of applying the signal applied to the oscillator in step (2) to a second slope detector circuit that exhibits a second current slope function opposite in polarity to that of the load line but which intersects the load line at a different equilibrium point; and wherein step (4) comprises the step of generating a second difference signal representing a difference between the chaotically modulated signal received in step (1) and the output of the second slope detector circuit.

137. A chaotic receiving circuit, comprising:

an input terminal that receives a chaotically modulated signal;

a resistor coupled to the input terminal, wherein the resistor defines a current-voltage load line;

an oscillator circuit coupled to the input terminal through the resistor and driven by the chaotically modulated signal;

a chaotic circuit comprising an upper slope circuit that implements a first current-voltage function in an upper quadrant of a current-voltage response plane and a lower slope circuit that implements a second current-voltage function in a lower quadrant of the current-voltage response plane, wherein the first and second current-voltage functions have a positive slope but are offset by a voltage difference and respectively intersect the current-voltage load line in the upper and lower quadrants of the current-voltage response plane;

a synchronizing circuit, coupled to the oscillator circuit and the chaotic circuit, wherein the synchronizing circuit detects differences between the chaotically modulated signal and signals respectively present at the upper and lower slope circuits; and

a detector coupled to the synchronizing circuit which recovers an information signal on the basis of the differences.

138. The chaotic receiving circuit of claim 137, further comprising a plurality of upper slope detector circuits and a plurality of lower slope detector circuits,

wherein each upper slope circuit and each lower slope circuit intersects the current-voltage load line at a different point, each point corresponding to a symbol of information.

139. The chaotic receiving circuit of claim 137, wherein the detector comprises a first analog-to-digital converter coupled to an output of the oscillator circuit, a second analog-to-digital converter coupled to upper slope circuit, and a third analog-to-digital converter coupled to the lower slope circuit, wherein the outputs of the first, second, and third analog-to-digital converters are used to recover the information signal.

140. The method of claim 1, wherein step (1) comprises the step of using a circuit that exhibits a positive linear slope, and wherein step (2) comprises the step of changing the positive linear slope.

141. The apparatus of claim 15, wherein the chaotic circuit exhibits a positive linear slope.

142. The apparatus of claim 25, wherein the chaotic circuit exhibits a positive linear slope.

143. The apparatus of claim 75, wherein the first chaotic circuit exhibits a first positive linear current slope that is offset to intersect a load line in an upper quadrant of a current-voltage characteristic curve; and wherein the second chaotic circuit exhibits a second positive linear current slope that is offset to intersect the load line in a lower quadrant of the current-voltage characteristic curve.

144. A method of transmitting information, comprising the steps of:

(1) generating a chaotic carrier signal characterized by a voltage that oscillates chaotically about a first equilibrium point in a current-voltage plane, wherein the first equilibrium point is defined by an intersection of a current-voltage load line having a first slope and a current-voltage slope line having a second slope opposite in polarity to that the of the first slope;

(2) in response to a time-varying information signal comprising an N-bit symbol, selecting one of a plurality of 2^N equilibrium points defined by successive intersections of a plurality of current-voltage slope lines having slopes opposite to

that of the load line and that intersect the load line at different points;

(3) shifting the first equilibrium point to the one selected equilibrium point such that the chaotic carrier signal oscillates chaotically about the one selected equilibrium point; and

(4) transmitting the chaotic carrier signal shifted in step (3).

145. The method of claim 144, wherein step (3) comprises the step of changing a nonreactive circuit value in a chaotic circuit coupled to a resistor that defines the current-voltage load line.

146. The method of claim 144, further comprising the steps of:

(5) receiving the signal transmitted in step (4);

(6) determining which of the plurality of equilibrium points corresponds to the signal received in step (5); and

(7) on the basis of the determination in step (6), generating an information symbol.

147. Apparatus for transmitting a modulated chaotic signal, comprising:

a computer that generates, in response to an information signal, a digital word comprising N bits;

a digital-to-analog converter, coupled to the computer, that converts the digital word into an analog signal selected from one of 2^N possible signal levels; and

means for converting the analog signal into a chaotically oscillating signal that oscillates about a current-voltage equilibrium point defined by an intersection of a resistive load line and a current-voltage function uniquely defined by the analog signal.

148. A method of interfacing a chaotic transmitting circuit to a communications channel without using a frequency filter, comprising the steps of:

(1) buffering an output of the chaotic transmitting circuit to isolate the chaotic transmitting circuit from the communications channel;

(2) removing a direct current voltage component from the buffered output obtained in step (1); and

(3) matching the amplitude and impedance of the signal obtained from step

(2) to the communications channel.

149. The method of claim 148, wherein step (2) comprises the step of using a direct current power supply and an attenuator circuit.

150. The method of claim 148, wherein step (3) comprises the step of using a balanced line driver to match the electrical characteristics of a twisted pair wire communications channel.

151. The method of claim 148, wherein step (3) comprises the step of matching the amplitude and impedance of the signal obtained from step (2) to a light emitting diode.

152. Apparatus for interfacing a chaotic transmitting circuit to a communications channel without using a frequency filter, comprising:

an isolation circuit that buffers an output of the chaotic transmitting circuit from the communications channel;

a direct current power supply coupled to the isolation circuit through a resistor, wherein the direct current power supply subtracts a direct current voltage from the output of the isolation circuit; and

an attenuator circuit, coupled to the direct current power supply, wherein the attenuator circuit attenuates a signal present at the direct current power supply prior to being introduced into the communications channel.

153. The apparatus of claim 152, wherein the communications channel comprises a cable system.

154. The apparatus of claim 152, further comprising a balanced line driver that matches the electrical characteristics of the apparatus to a dual conductor cable.

155. The apparatus of claim 152, wherein the communications channel comprises a radio frequency channel.

156. A method of interfacing a chaotic receiving circuit to a communications channel without using a frequency filter, comprising the steps of:

(1) buffering a modulated chaotic signal received from the communications channel to isolate the chaotic receiving circuit from the communications channel;

(2) amplifying the buffered signal; and

(3) adding a direct current component to the amplified buffered signal obtained in step (2), wherein the direct current component corresponds to a direct current component subtracted at a corresponding transmitter.

157. The method of claim 156, further comprising the step of, prior to step (1), passing the modulated chaotic signal through a balanced input buffer/amplifier that matches electrical characteristics of a dual conductor communications channel to the chaotic receiving circuit.

158. Apparatus for interfacing a chaotic receiving circuit to a communications channel without using a frequency filter, comprising:

a buffering circuit that buffers a modulated chaotic signal received from the communications channel to isolate the chaotic receiving circuit from the communications channel;

an amplifier coupled to the buffering circuit that amplifies an output of the buffering circuit; and

a direct current voltage offset circuit coupled to the amplifier, wherein the direct current voltage offset circuit adds a direct current component to the amplified buffered signal, wherein the direct current component corresponds to a direct current component subtracted at a corresponding transmitter.

159. The apparatus of claim 158, further comprising a differential input amplifier, coupled to the buffering circuit, wherein the differential input amplifier rejects common-mode input components and amplifies differential components.